PSD Characterization and Optimization of Stilbene Crystals with Silicon Photomultiplier Readout

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Motivation and Introduction

- **Stilbene Crystals**, when compared to xylene-based organic scintillators, e.g. EJ309 [1], feature
  - excellent **gamma-neutron discrimination**
  - good neutron detection efficiency
- **Silicon Photomultiplier (SiPM)** detectors are
  - compact, single-photon sensitive materials
  - a candidate to replace conventional PMTs
  - Enabling designs for **compact radiation detection and measurement devices** that would be impossible with bulky, high voltage PMTs, such as handheld imagers
- **Goal:** report **pulse shape discrimination (PSD) performance** of the detection assembly, as a function of pulse post-processing parameters, crystal size and SiPM voltage bias.

Methods

- Detector assembly
  - SensL C series 6mmx6mm SiPM
  - Stilbene crystals of various shapes/sizes

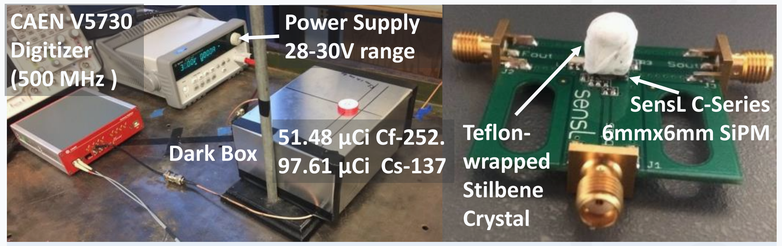


Fig. 1 Irradiation setup (left) and SiPM coupled to a 6x6 mm^2 crystal (right)

Fig. 2 PSD parameters define tail and total integral boundaries

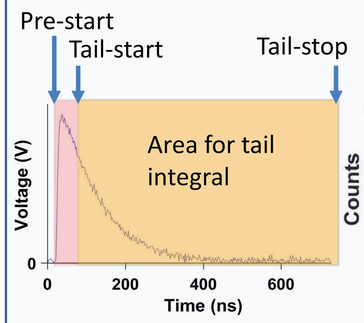


Fig. 3 PSD histogram and parameters used to calculate the FOM with: 6x6mm Crystal, 30V Bias, 600-800 keVee Slice

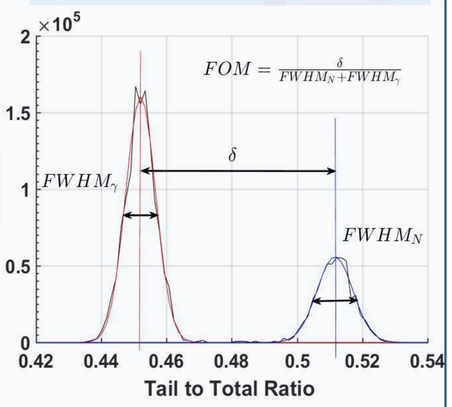


Figure of Merit Error Estimation

- **Cramer-Rao lower bound** [3] can be used to calculate the minimum variance of the estimated σ , i.e. $var(\hat{\sigma})$, as in Eq. 1
- $p(y;\sigma)$ is the probability density function of the signal, parametrized by the standard deviation of the distribution.

$$var(\hat{\sigma}) = \frac{1}{-E\left(\frac{\partial^2 p(y;\sigma)}{\partial \sigma^2}\right)} \qquad \text{Eq. 1}$$

Results

Fig: 4 shows greater light collection for smaller crystals.

- Pulse integral distribution for a Cs-137 irradiation
- Counts normalized to 80% of the Compton edge peak
- Length by height for rectangular crystals, length by diameter for cylindrical

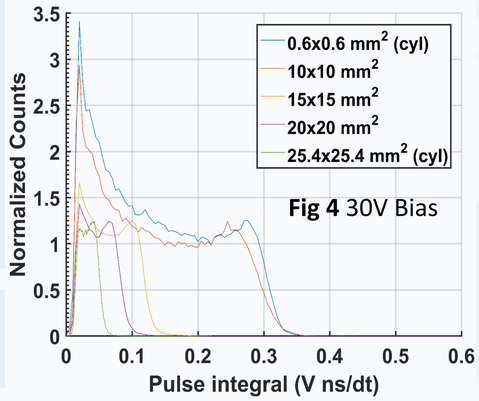


Fig 4 30V Bias

Fig: 5 shows PSD sensitivity to tail start time. Scatter plot of tail/total ratio vs pulse integral

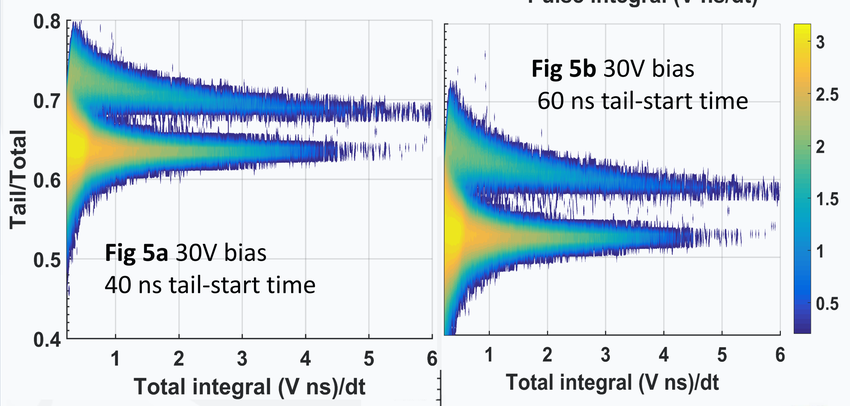


Fig 5a 30V bias
40 ns tail-start time

Fig 5b 30V bias
60 ns tail-start time

- **FOM** was obtained for
  - Pre-start 6,10,14 ns
  - Tail-stop time 6, 7, 8E2 ns
  - Tail-start times 40 -200 ns
  - Bias Voltage 28-30V
  - Slices from 0-2000 keVee
- The most robust parameters over all settings were selected, and shown in Fig 6.

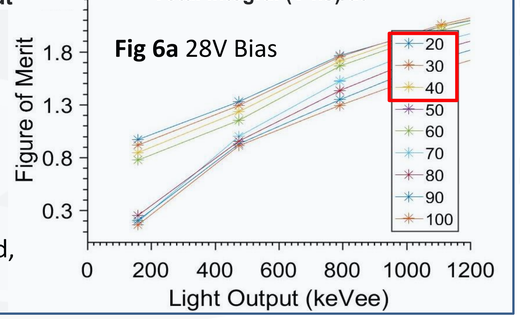


Fig 6a 28V Bias

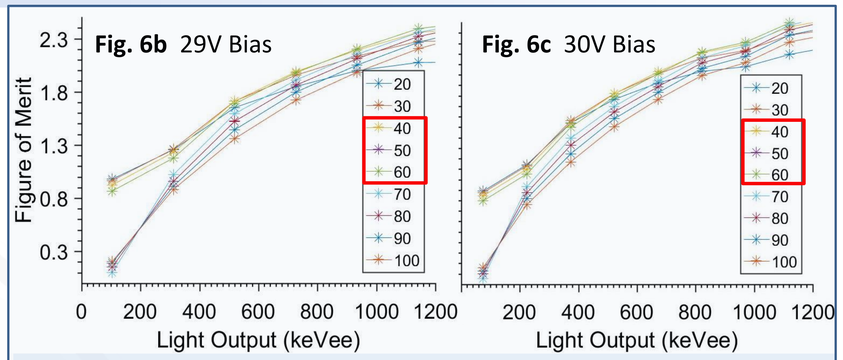
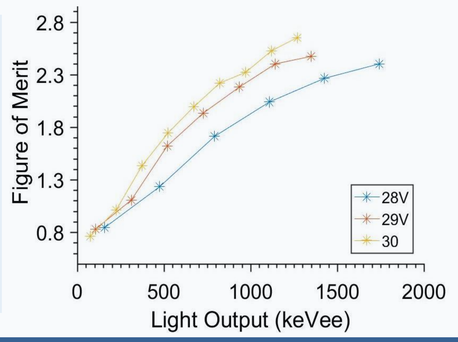


Fig 6: FOM of 6mmx6mm cylindrical crystal, irradiated with Cf-252, Varying PSD parameters. **Legend in Samples = 2 ns**

Fig. 7: FOM over low-energy slices for all 3 bias voltages with most robust settings

- **Tail-start time: 80 ns**
- Tail-stop time 800 ns
- Pre-start time 6 ns
- Window 1040 ns
- 6mmx6mm cylindrical crystal



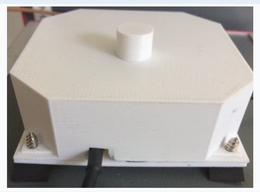
Conclusions and Future Work

- Small crystals (< 3.4 cm^3 volume) feature a better light collection compared to larger ones.
- Pulse shape discrimination is especially challenging for light output values less than 0.5 MeVee.
- Parameters which maximize the figure-of-merit, across all bias voltages, in the energy range of interest, are:
  - **Pre-start time: 6 ns**
  - **Tail-stop time: 800 ns**
  - **Tail-start time: 80 ns**

Future Work: evaluate and optimize PSD performance using light guides to couple the 6mmx6mm SiPM to larger area stilbene crystals

Fig 6 (right): 3D printed box for light guide coupling

Fig 7 (left): 20mm diameter cylinder stilbene crystal, coupled to light guide, coupled to SiPM



References:
[1] M. M. Bourne, S. D. Clarke, N. Adamowicz, S. A. Pozzi, N. Zaitseva, and L. Carman, "Neutron Detection in a High-Gamma Field Using Solution-Grown Stilbene," NIMA, vol. 806, 2015.
[2] "Guide to the Expression of Uncertainty in Measurement JCGM 100:2008, GUM 1995 with minor corrections", 2008 by BIPM IEC IFCC ILAC ISO IUPAC IUPAP OIML.
[3] Kay, M., "Fundamentals of statistical signal processing", Prentice Hall, 1993.

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